

# Proton Form Factor Ratio: the Jlab Polarization Experiments

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***For the Hall A Collaboration***

***and the  $G_{Ep}$  Collaboration***

***SPIN 2002***

***BNL, September 10 , 2002***

# Outline

form factors

what has changed since 1998?

spectacular decrease of systematic uncertainty

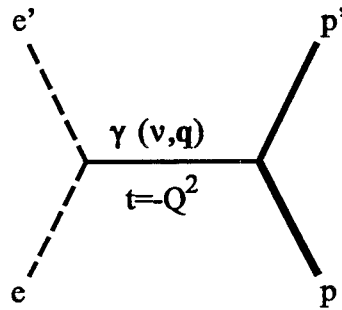
models of the nucleon reproduce the data,  
relativity is essential

pQCD quenching of  $F_2$  not seen yet.

Are we seeing the orbital angular momentum of the  
quarks, or is it just a mixing of quark helicities due to  
relativity?

on the road to higher  $Q^2$  .

# One-Step Process



**In one photon Exchange Approximation:**

**matrix element of e.m. hadronic current  $J_\mu$ ,**

$$\langle N(p') | J_\mu | N(p) \rangle = e \bar{u}(p') \left\{ \gamma_\mu F_1(Q^2) + \frac{i\kappa}{2m} \sigma_{\mu\nu} q^\nu F_2(Q^2) \right\} u(p)$$

**Two parts to current operator: helicity conserving  $F_1$  (Dirac) and spin-flip  $F_2$  (Pauli)**

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma}{d\Omega_{Mott}} \times \left\{ F_1^2(Q^2) + \tau \kappa^2 F_2^2(Q^2) + 2\tau \left( F_1(Q^2) + \kappa F_2(Q^2) \right)^2 \tan^2 \frac{\theta_e}{2} \right\}$$

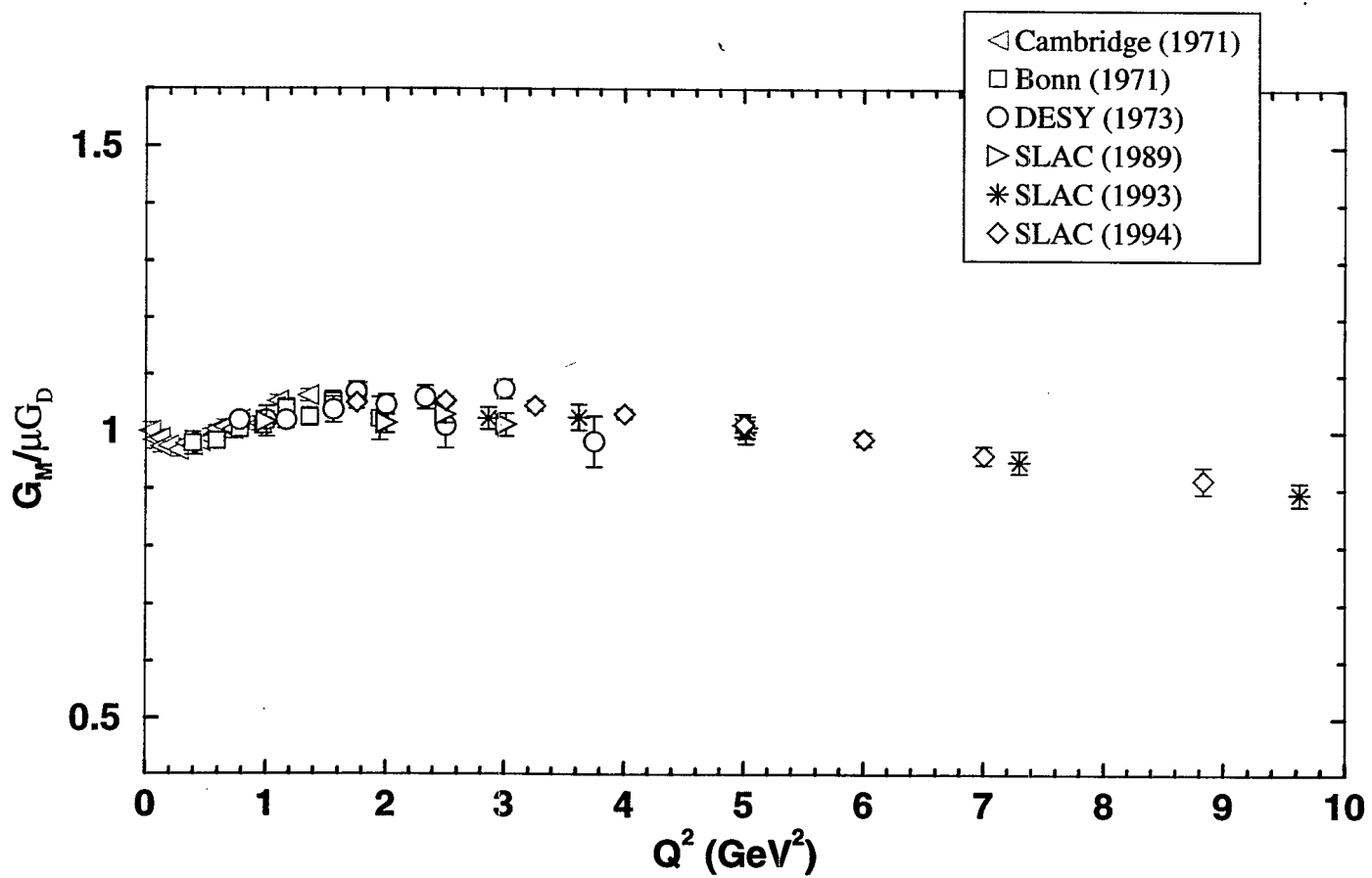
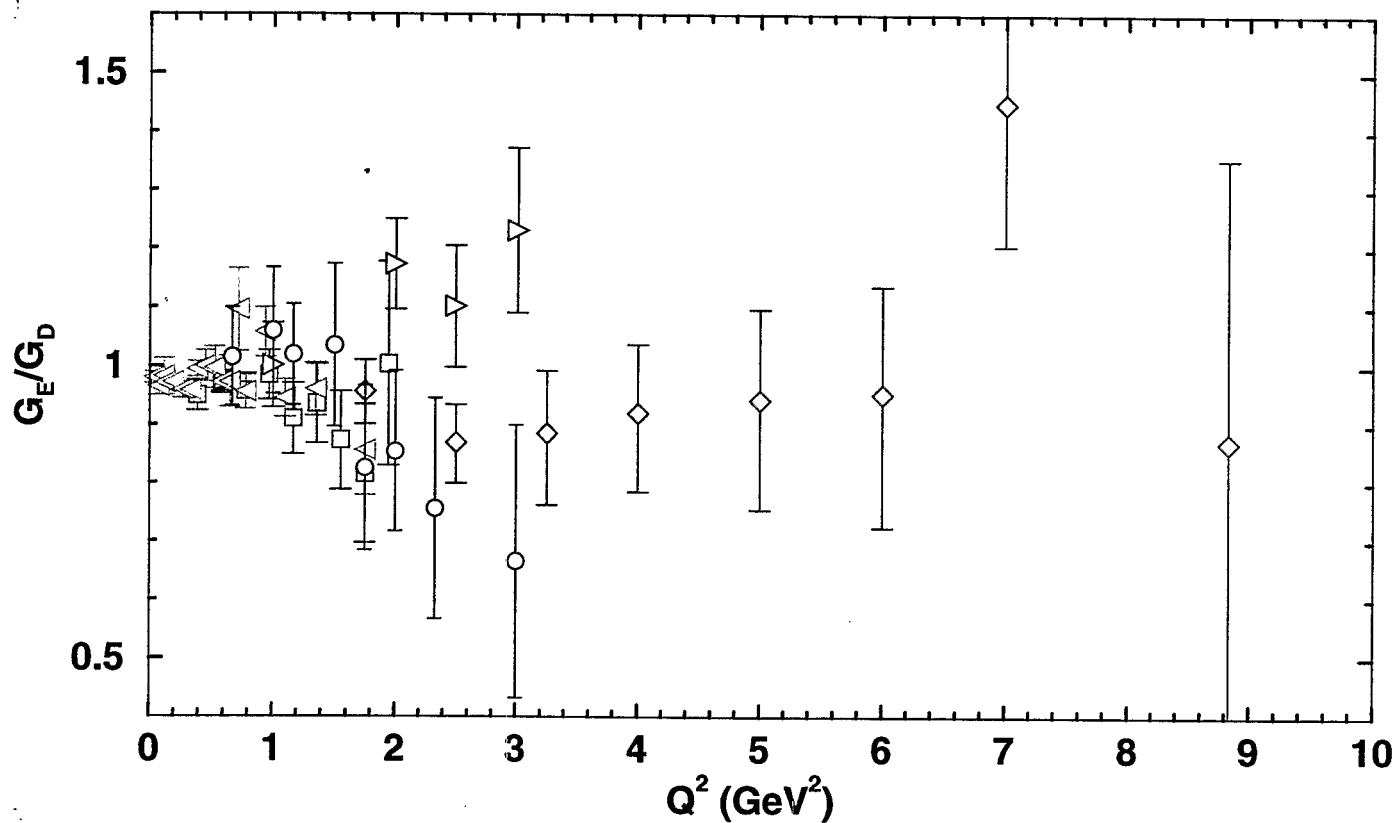
$$G_{\mathrm{Ep}} = F_1 - \tau \kappa_{\mathrm{p}} F_2$$

$$G_{\mathrm{Mp}} = F_1 + \kappa_{\mathrm{p}} F_2$$

$$\frac{\mathrm{d}\boldsymbol{\sigma}}{\mathrm{d}\boldsymbol{\Omega}} = \frac{\mathrm{d}\boldsymbol{\sigma}}{\mathrm{d}\boldsymbol{\Omega}_{\mathrm{ns}}} \left\{ G_{\mathrm{Ep}}^2 + \frac{\tau}{\varepsilon} G_{\mathrm{Mp}}^2 \right\}$$

$$\varepsilon = \frac{1}{1 + 2(1 + \tau) \tan^2 \frac{\theta_{\mathrm{e}}}{2}},$$

$$\tau = \frac{Q^2}{4\,m_{\mathrm{p}}^2}$$



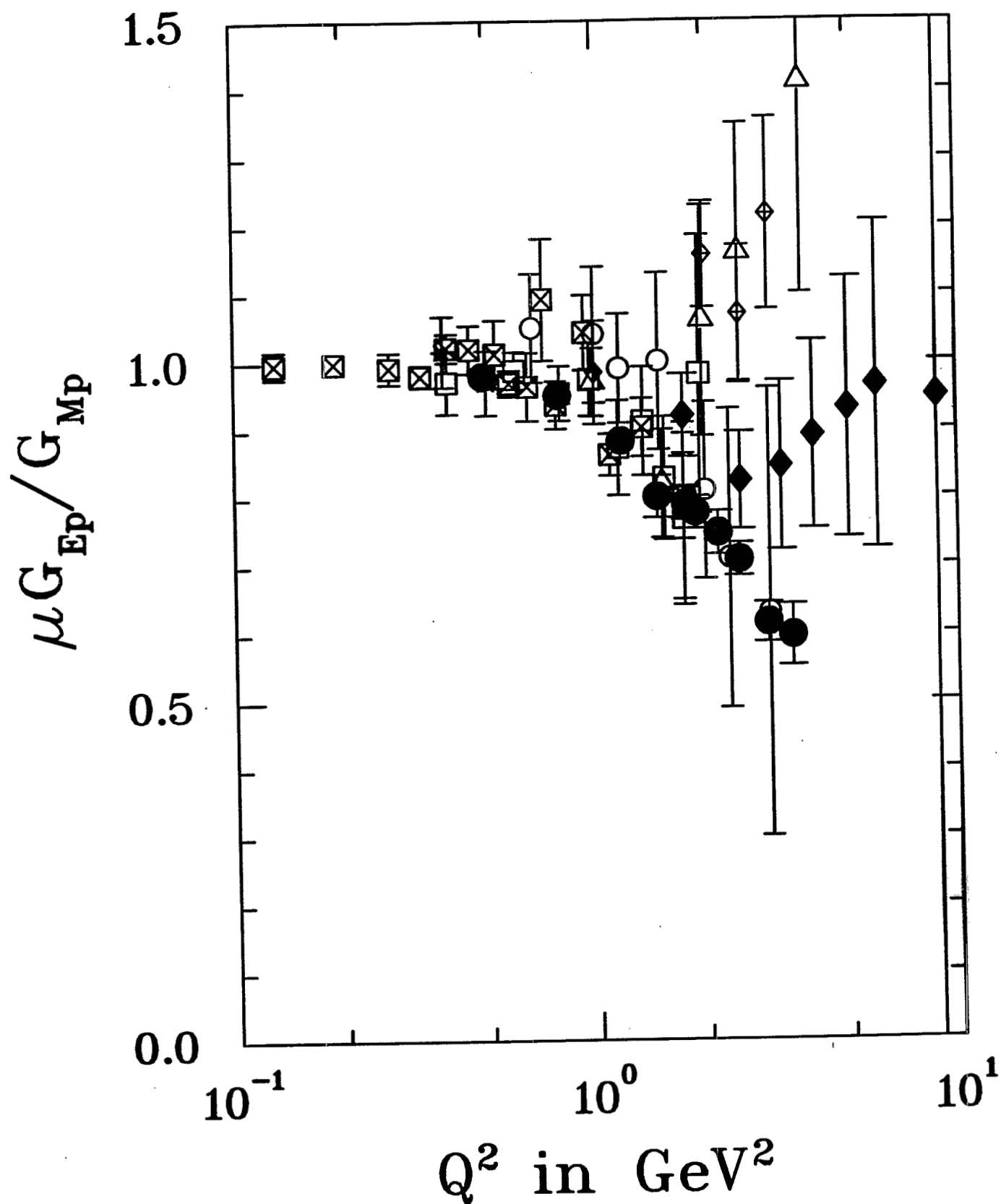
$$I_0 P_t = -2 \sqrt{\tau(1+\tau)} G_{E_p} G_{M_p} \tan \frac{\theta_e}{2}$$

$$I_0 P_\ell = \frac{E_e + E_{e'}}{m_p} \sqrt{\tau(1+\tau)} G_{M_p}^2 \tan^2 \frac{\theta_e}{2}$$

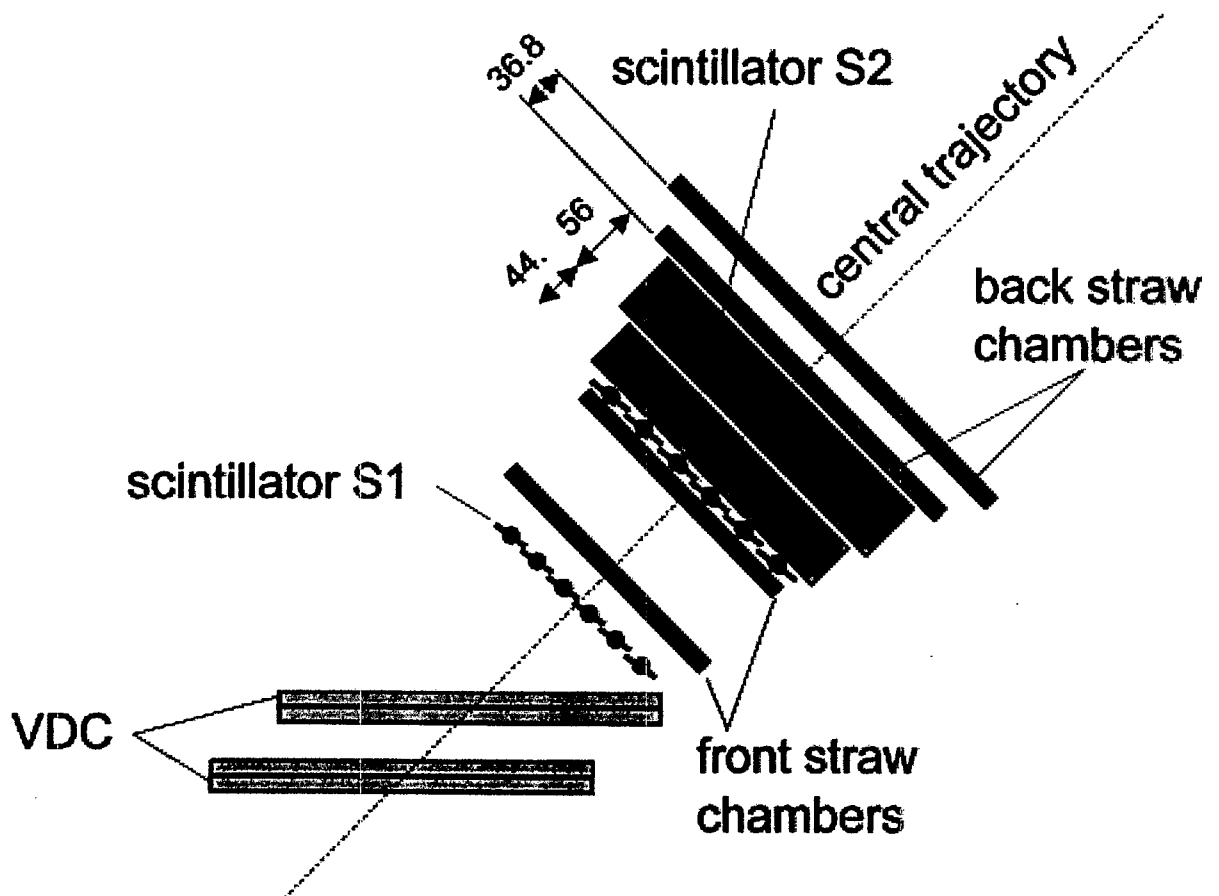
$$I_0 = G_{E_p}^2 (Q^2) + \frac{\tau}{\varepsilon} G_{M_p}^2 (Q^2)$$

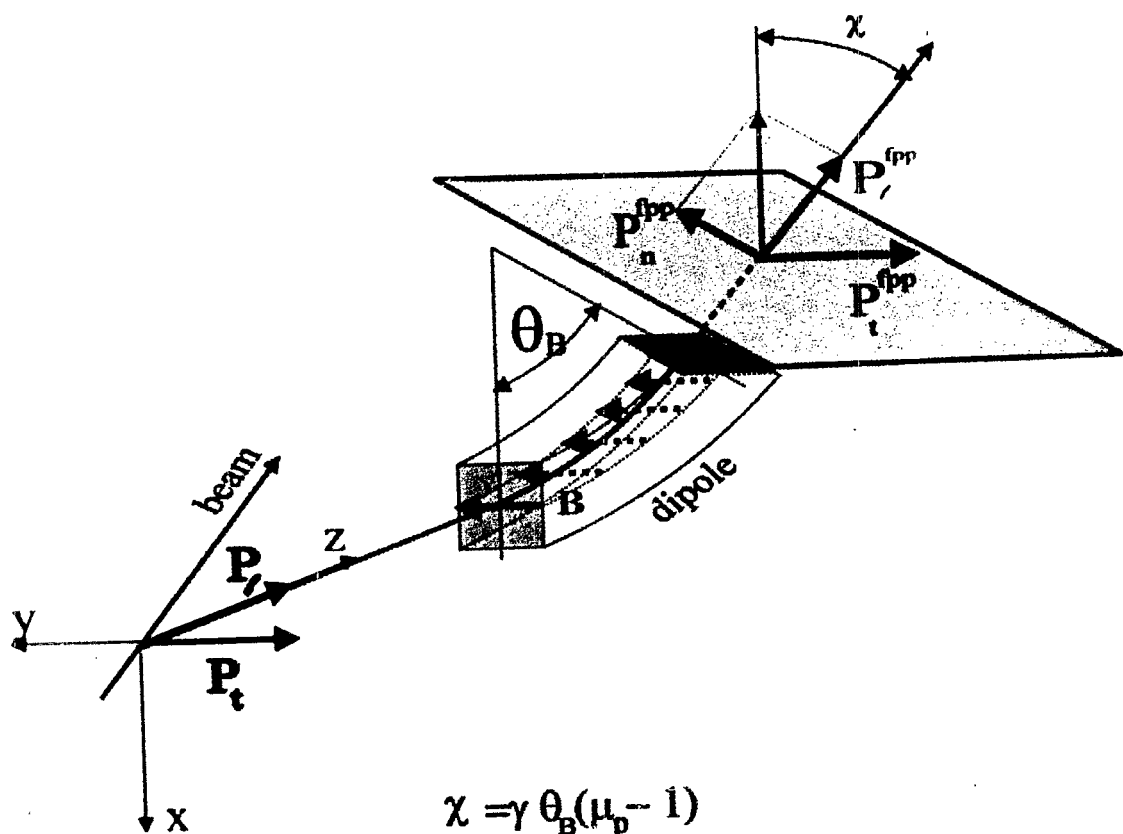
$$\frac{P_t}{P_\ell} = - \frac{G_{Ep}}{G_{Mp}} \frac{2m_p}{E_e + E_{e'}} \frac{1}{\tan(\theta_e / 2)}$$

$$\frac{F_2}{F_1} = \frac{1 - G_{Ep} / G_{Mp}}{\kappa_p (\tau + G_{Ep} / G_{Mp})}$$



## FPP for GEp(II)

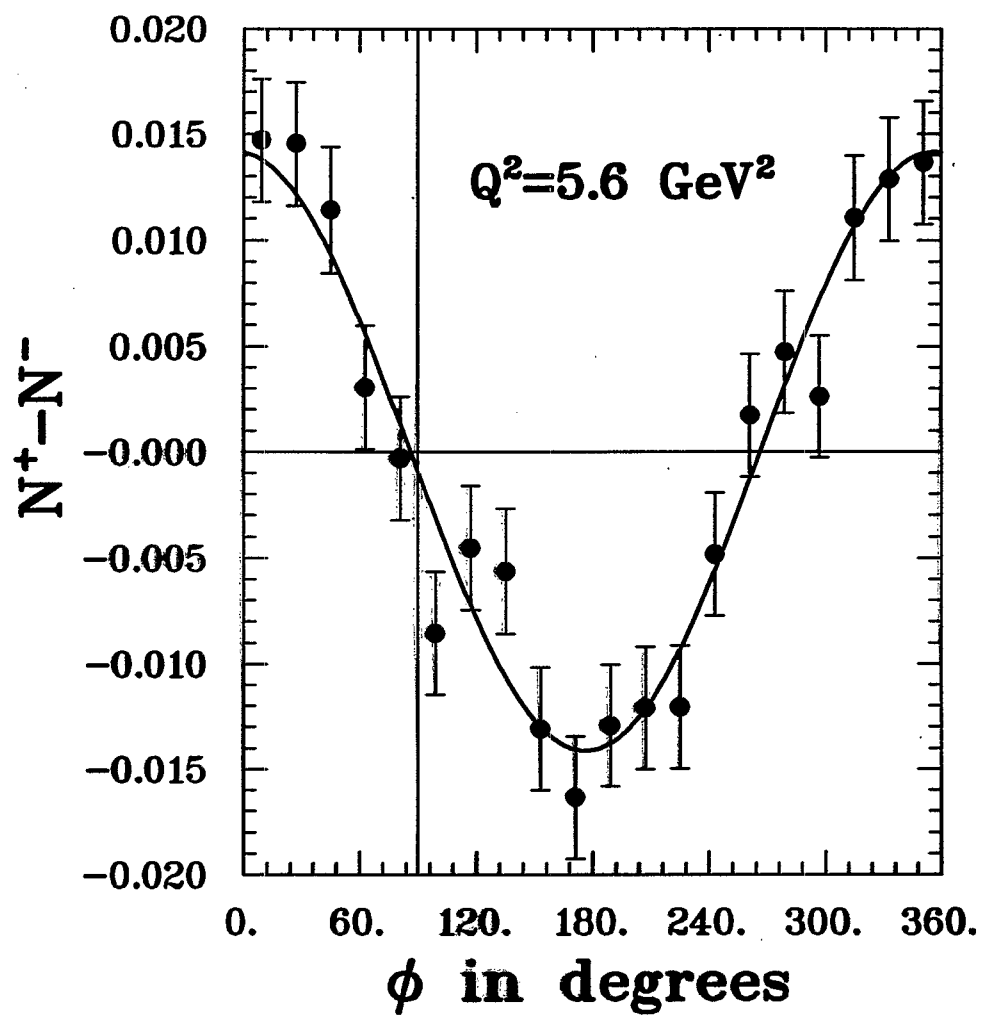




$$\chi = \gamma \theta_B (\mu_p - 1)$$

$$P_t^{fpp} = P_t$$

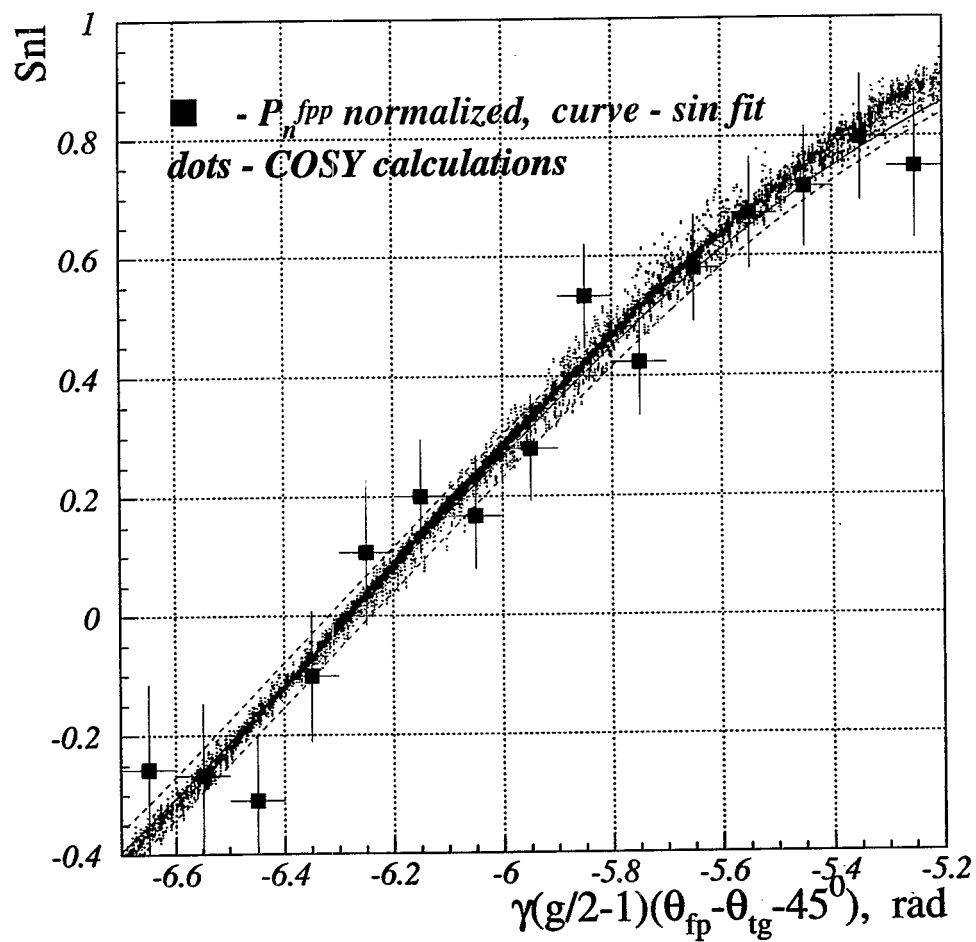
$$P_n^{fpp} = P_e \sin \chi$$

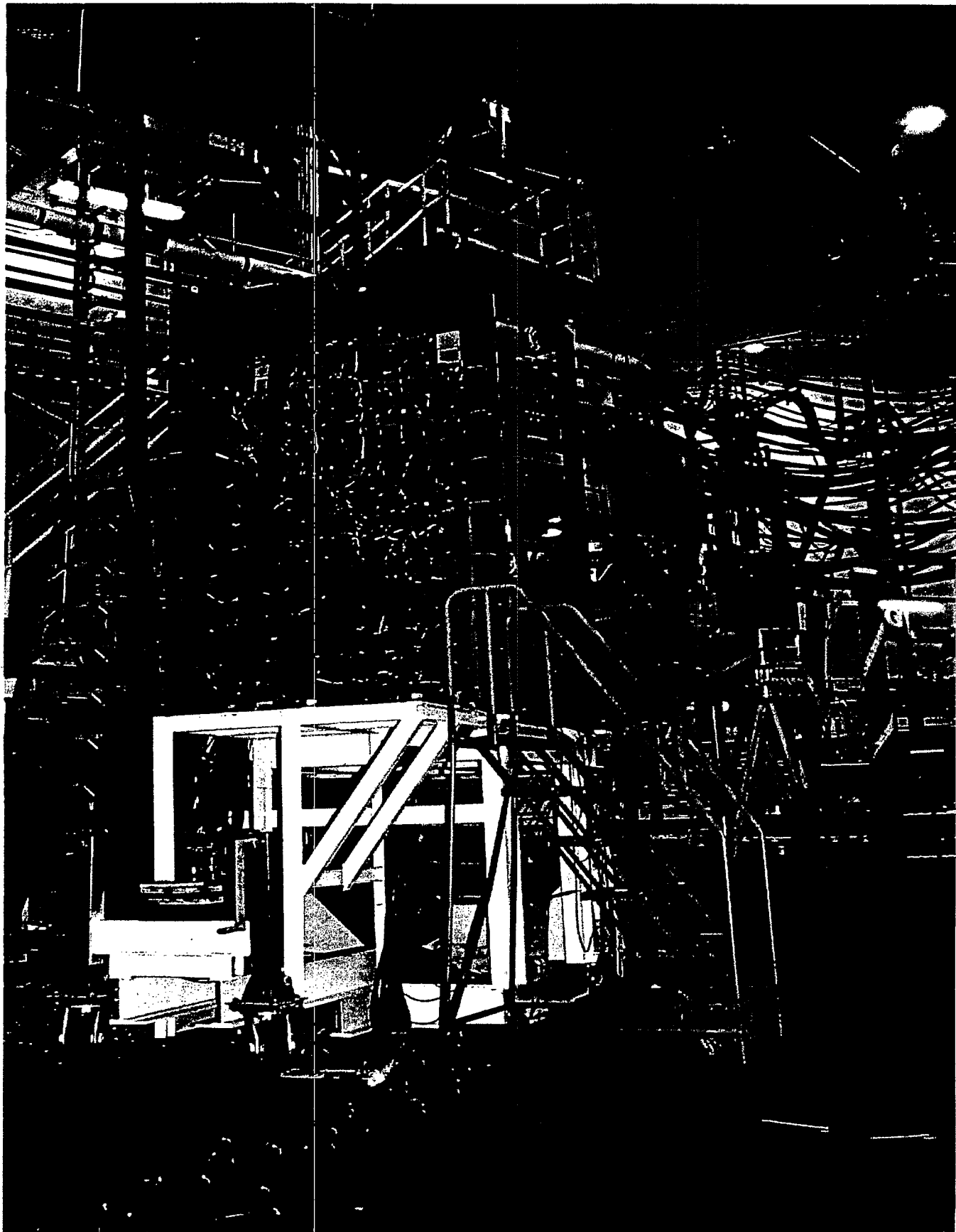


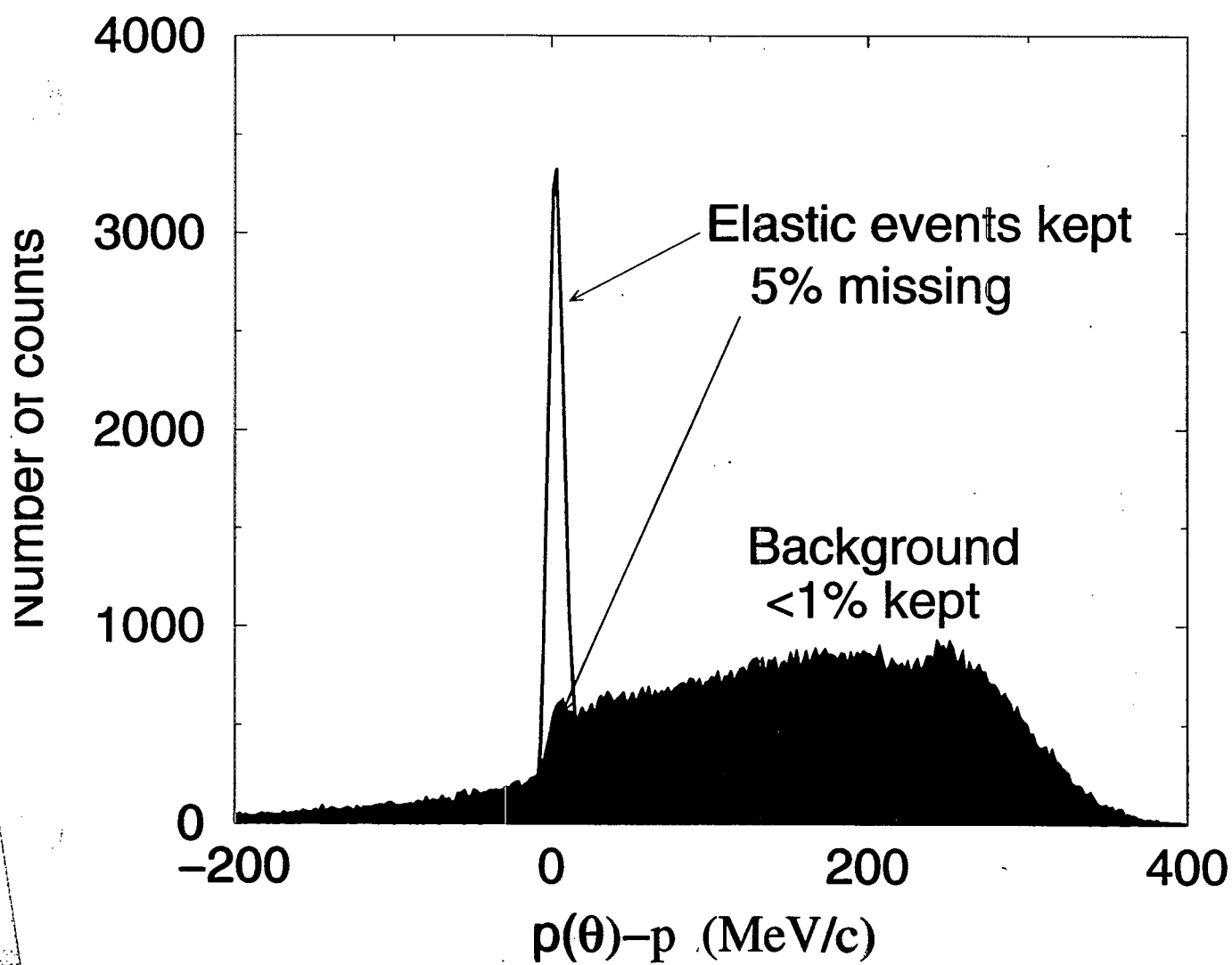
# TESTING COSY MODEL (dispersive plane)

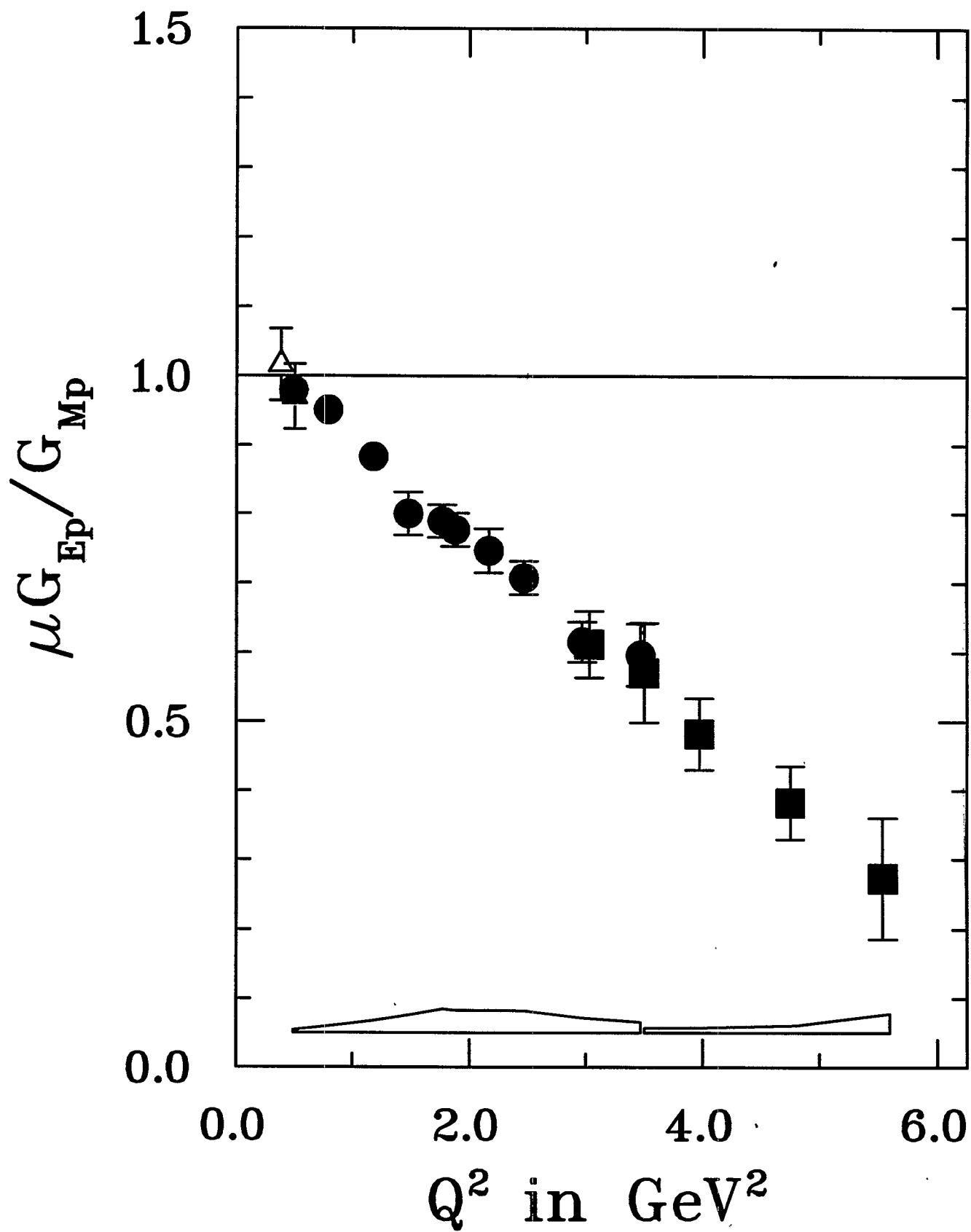
$$P_n^{fpp} \sim S_{nl}$$

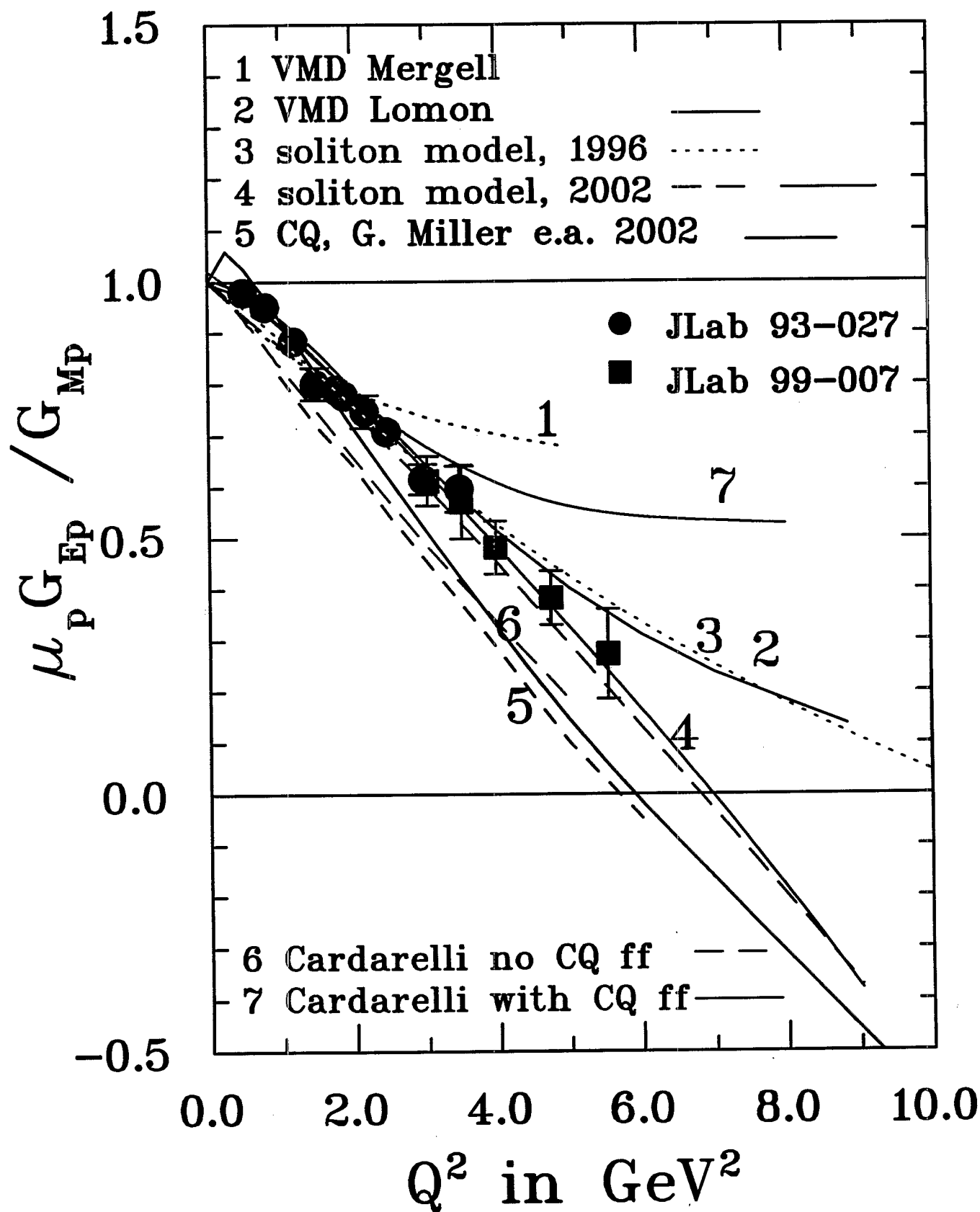
$$Q^2 = 5.6 \text{ GeV}^2:$$

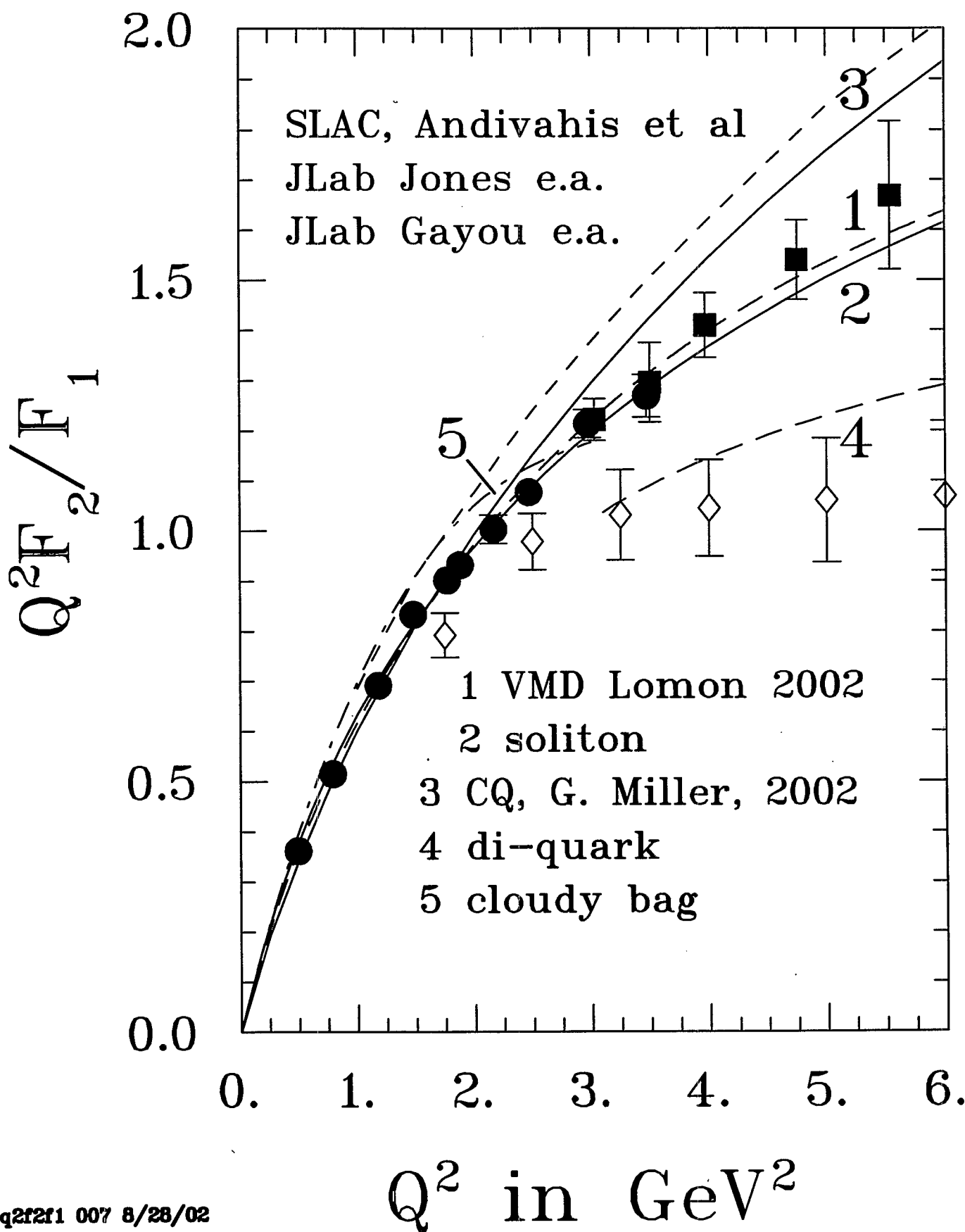


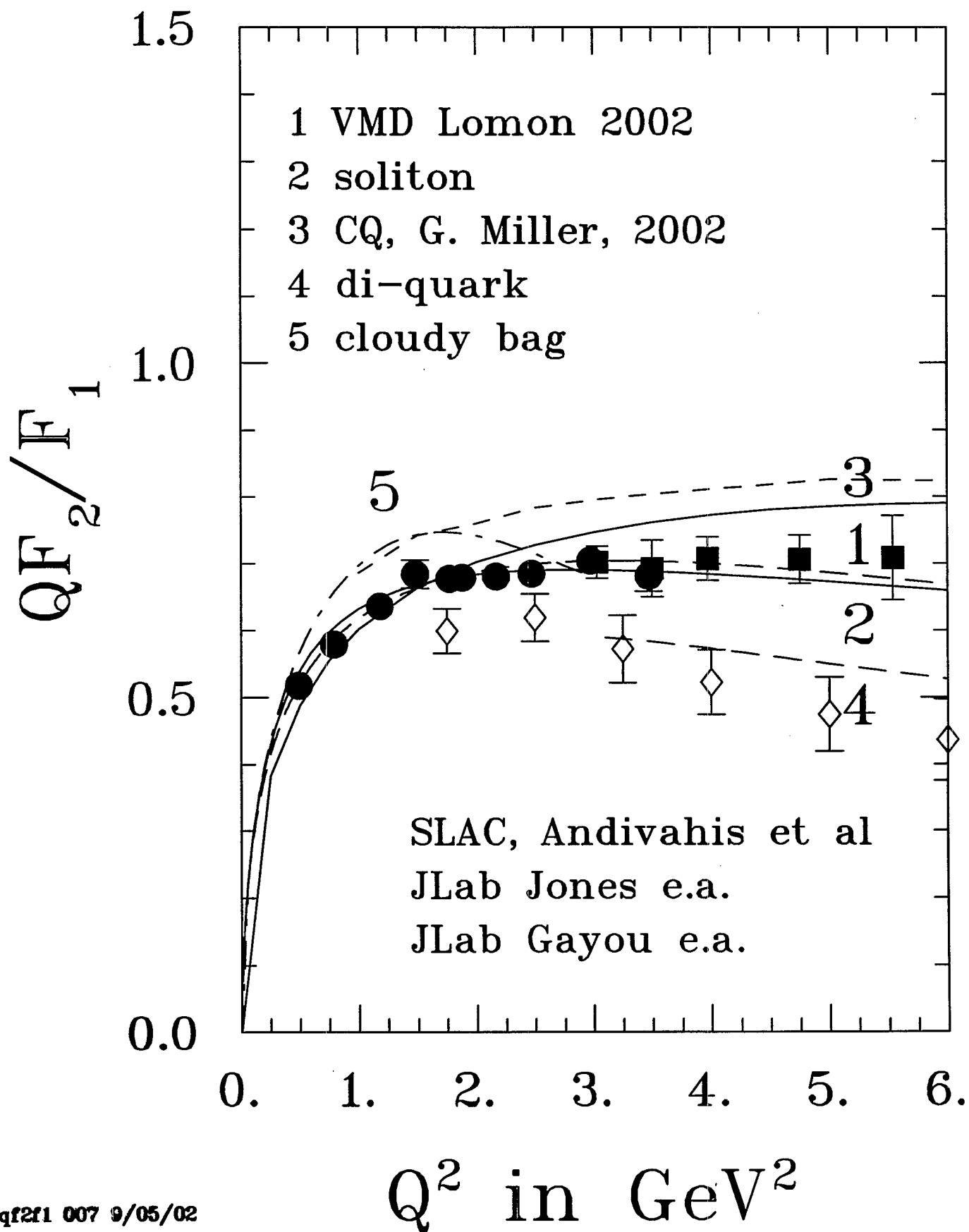


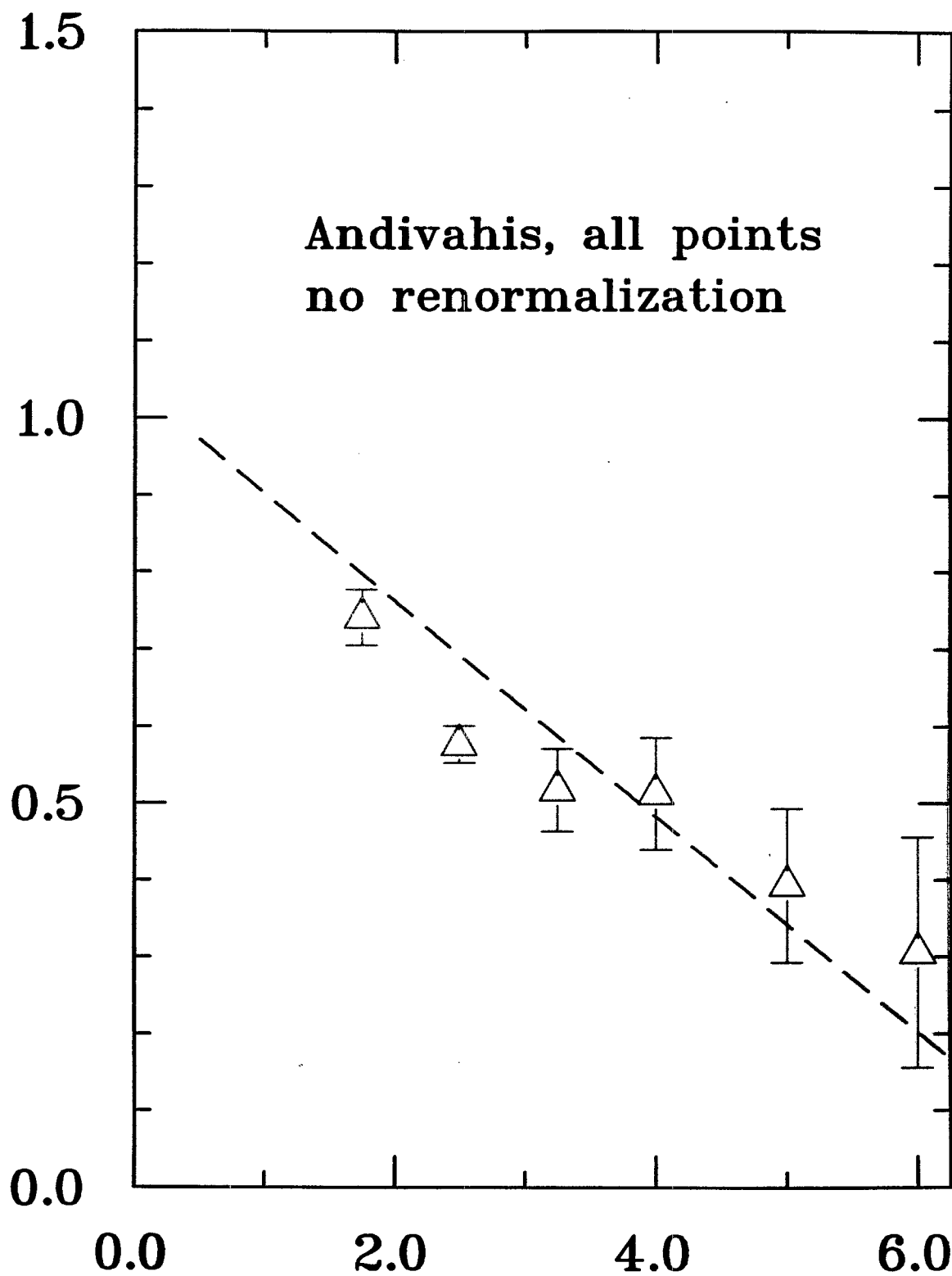


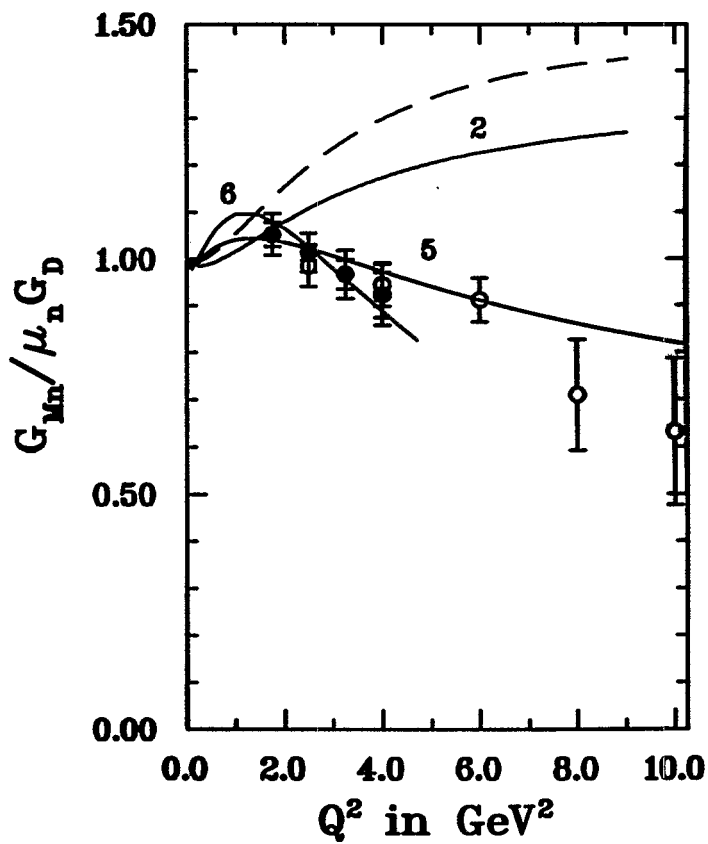
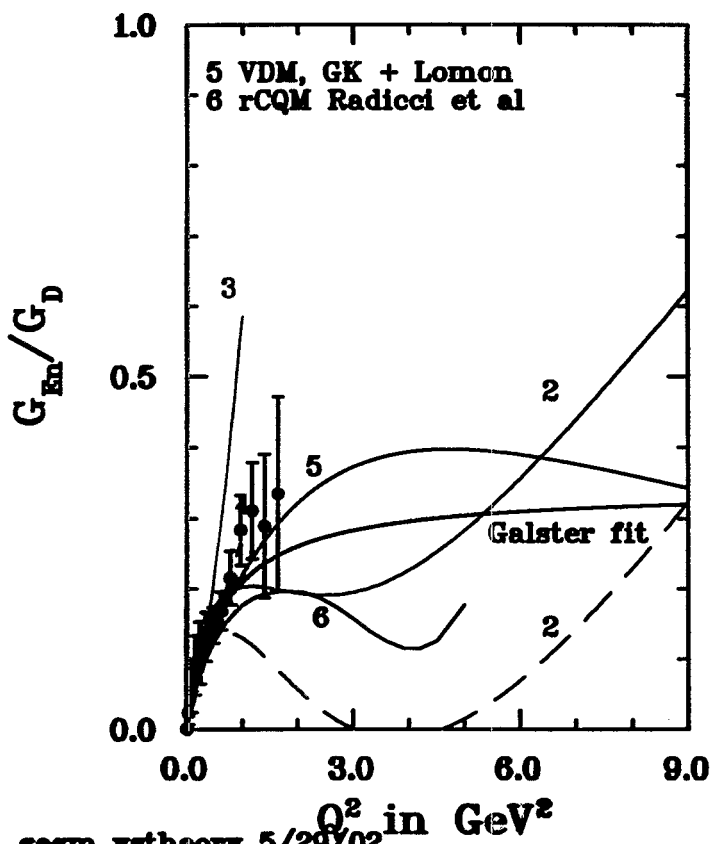
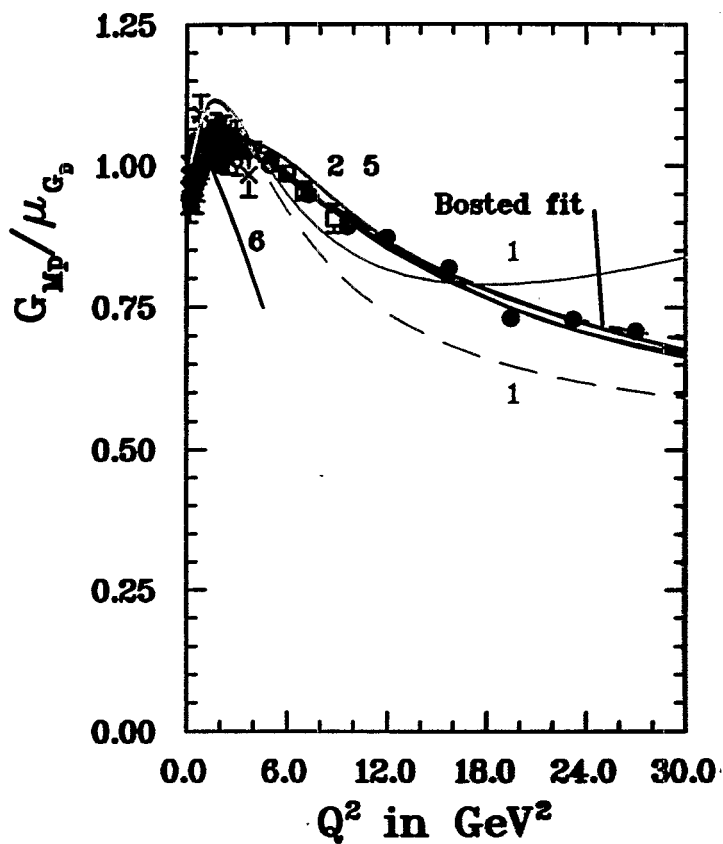
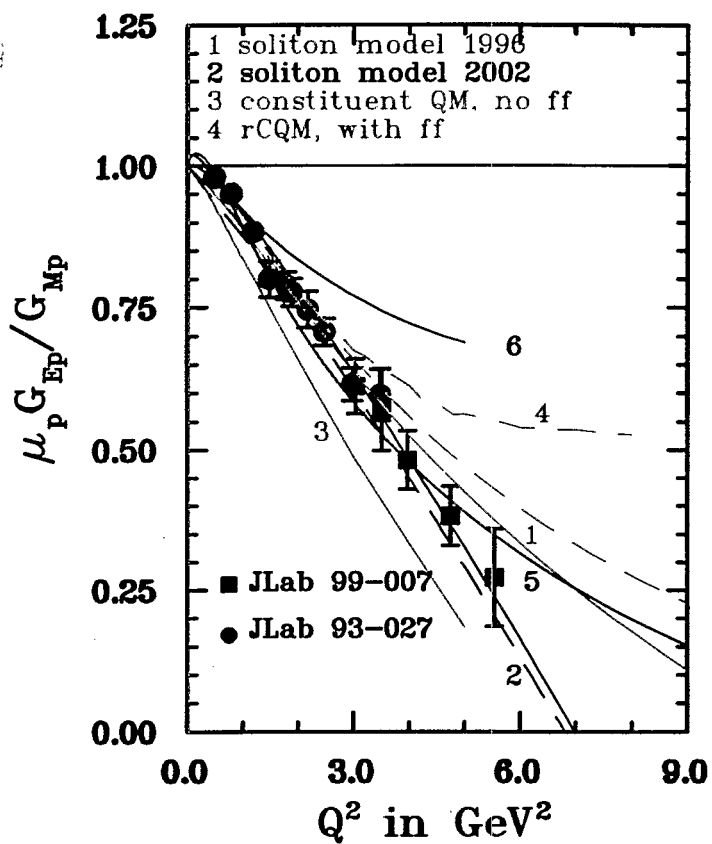


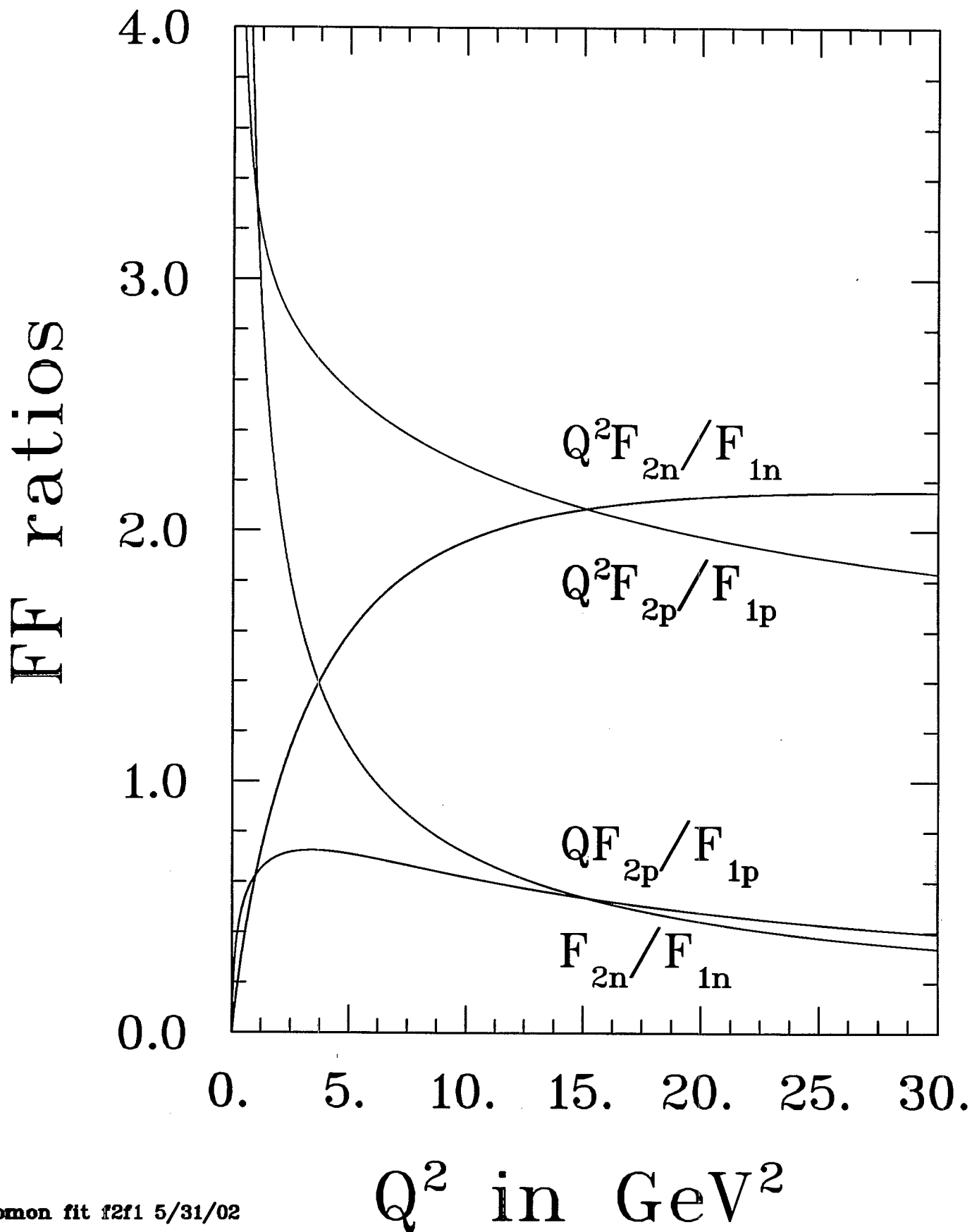












to  $Q^2=9 \text{ GeV}^2$

Experiment 01-109 in Hall C will be ready in early 2005

Requires new polarimeter in HMS detector hut

Optimize polarimeter efficiency: two FPP in series  
prototype drift chamber under construction in Dubna

Must detect every electron associated with a proton in the  
HMS acceptance: requires electron detector with 135 msr.

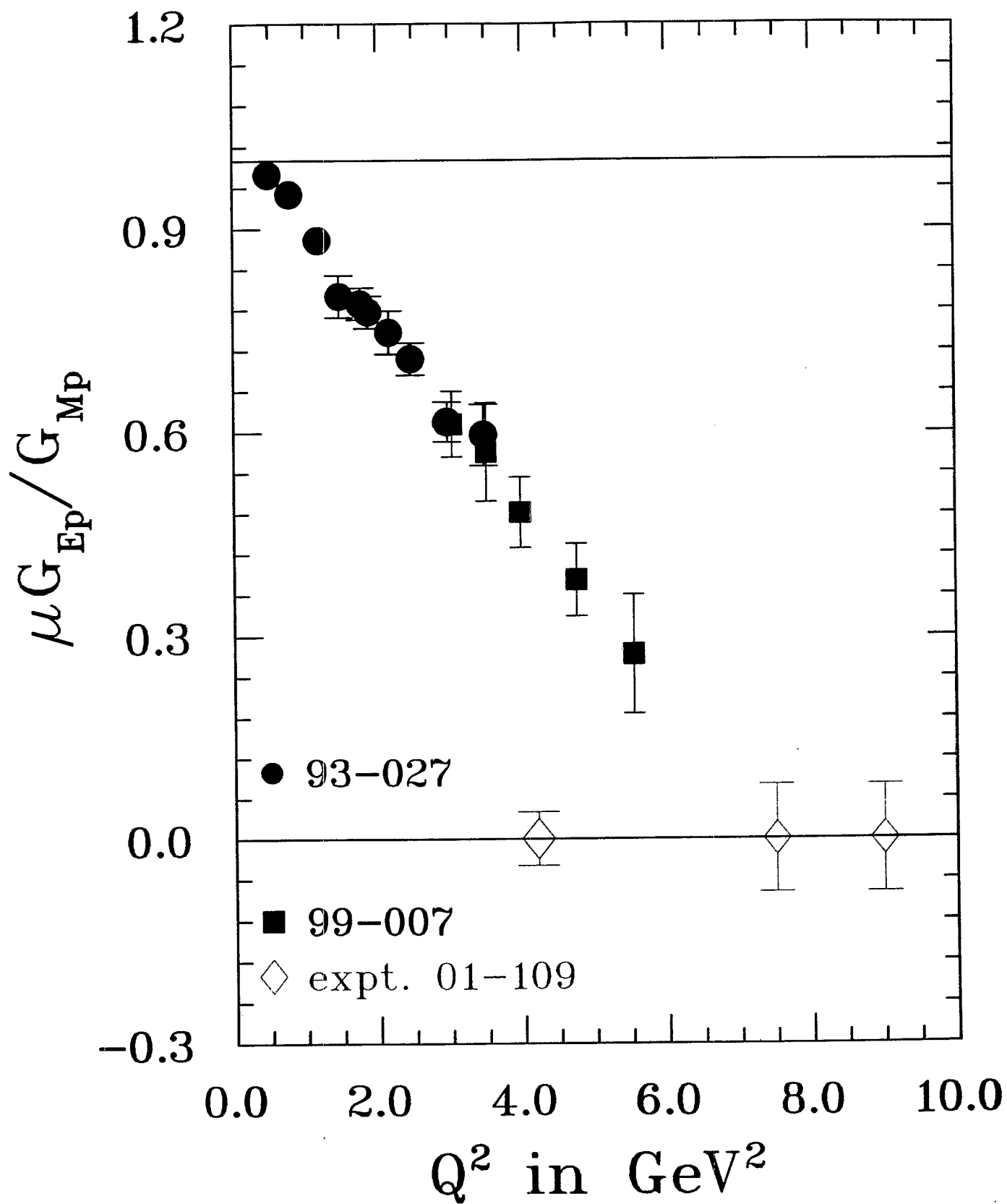
Calorimeter with 1744 lead glass bars of  $4 \times 4 \times 40$  (45)  $\text{cm}^3$   
currently being assembled at Jlab

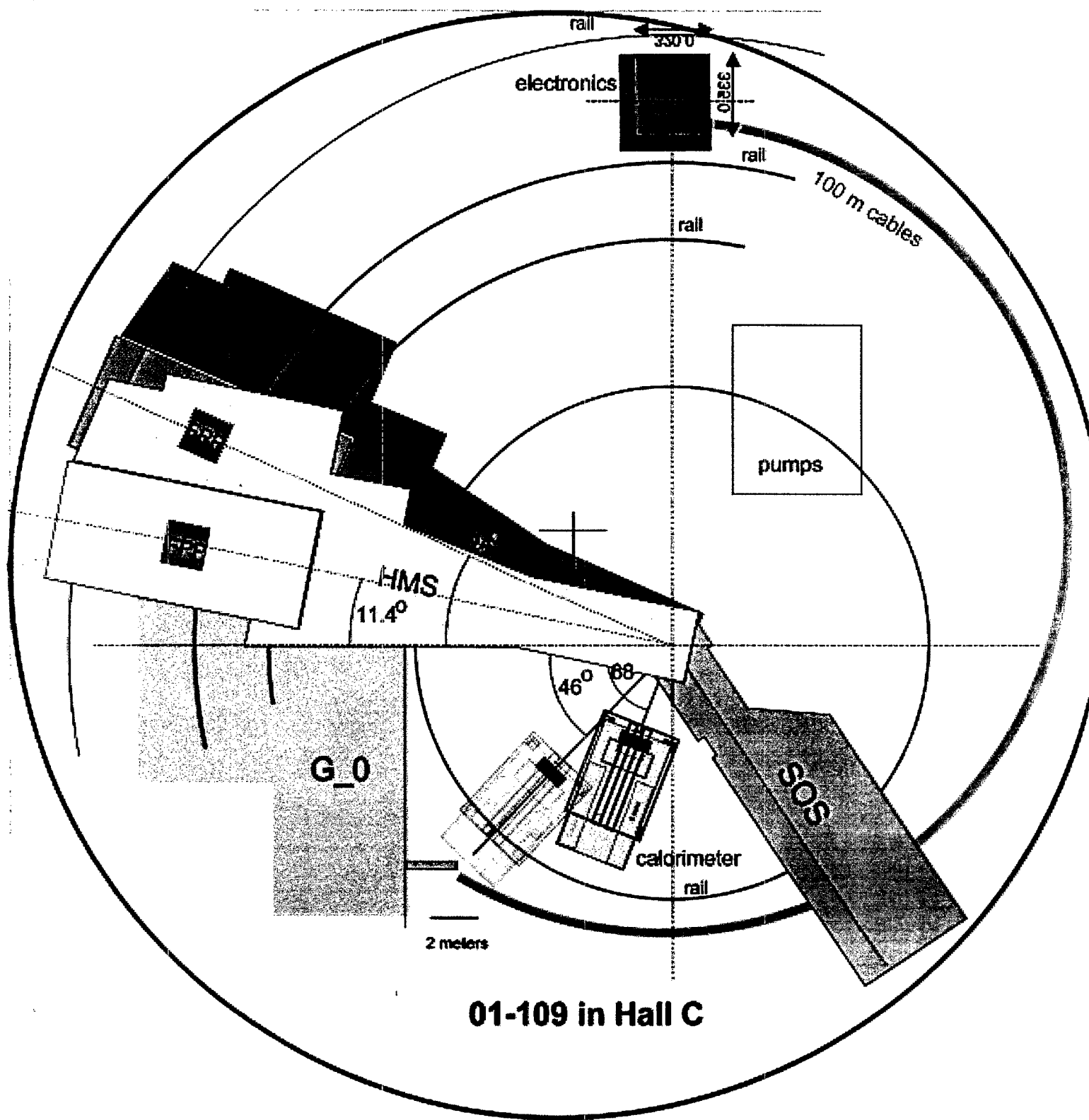
from recently built Hall A Real Compton Scattering  
calorimeter (Alan Nathan and Bogdan Wojtsekhowski  
e.a.)

from glass from Protvino collaborators (Valeri  
Kubarovsky e.a.)

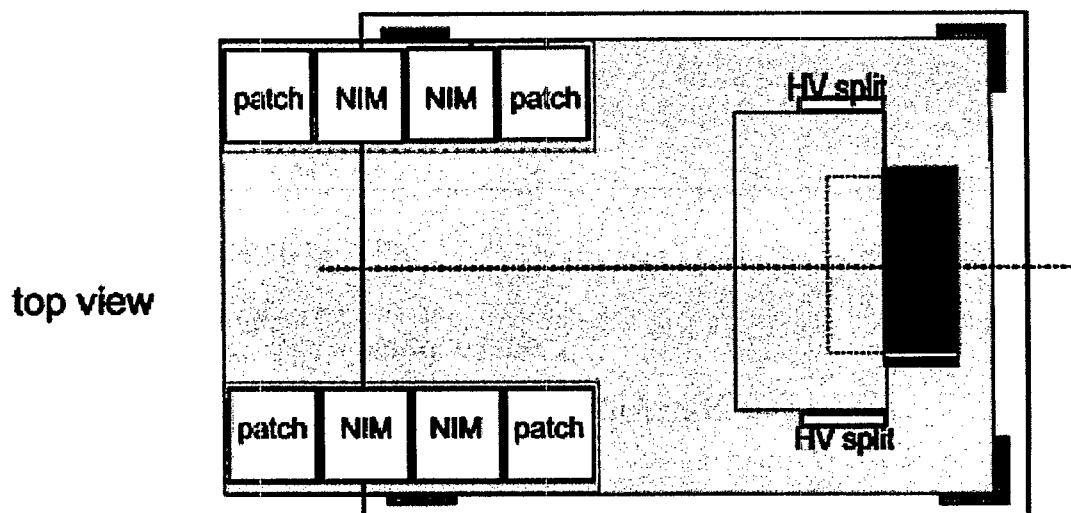
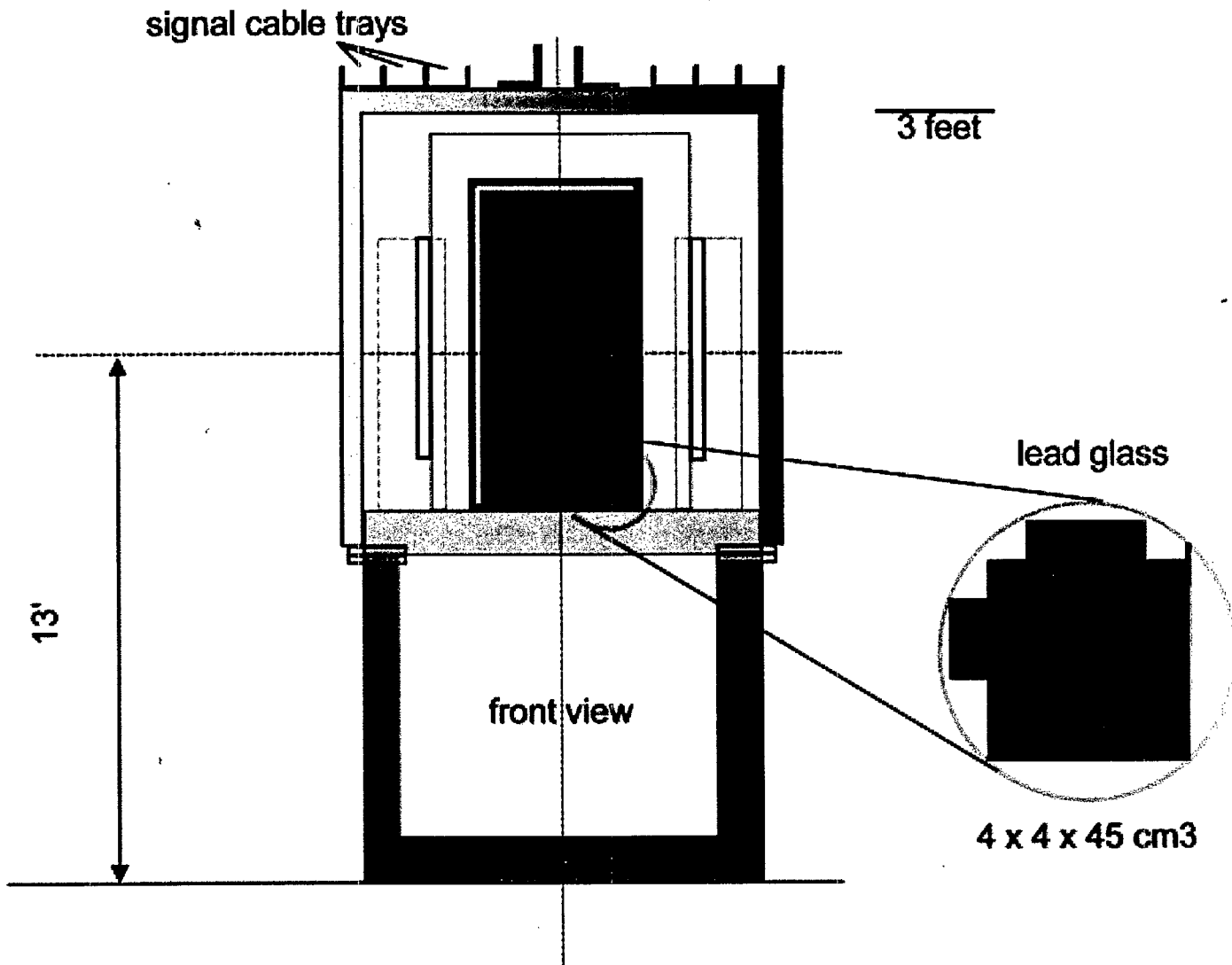
Position resolution 5 mm; ADCs on every PM but 1 TDC  
per 8 bars. Energy resolution not important here.

Design and construction of both polarimeter and  
calorimeter has started.

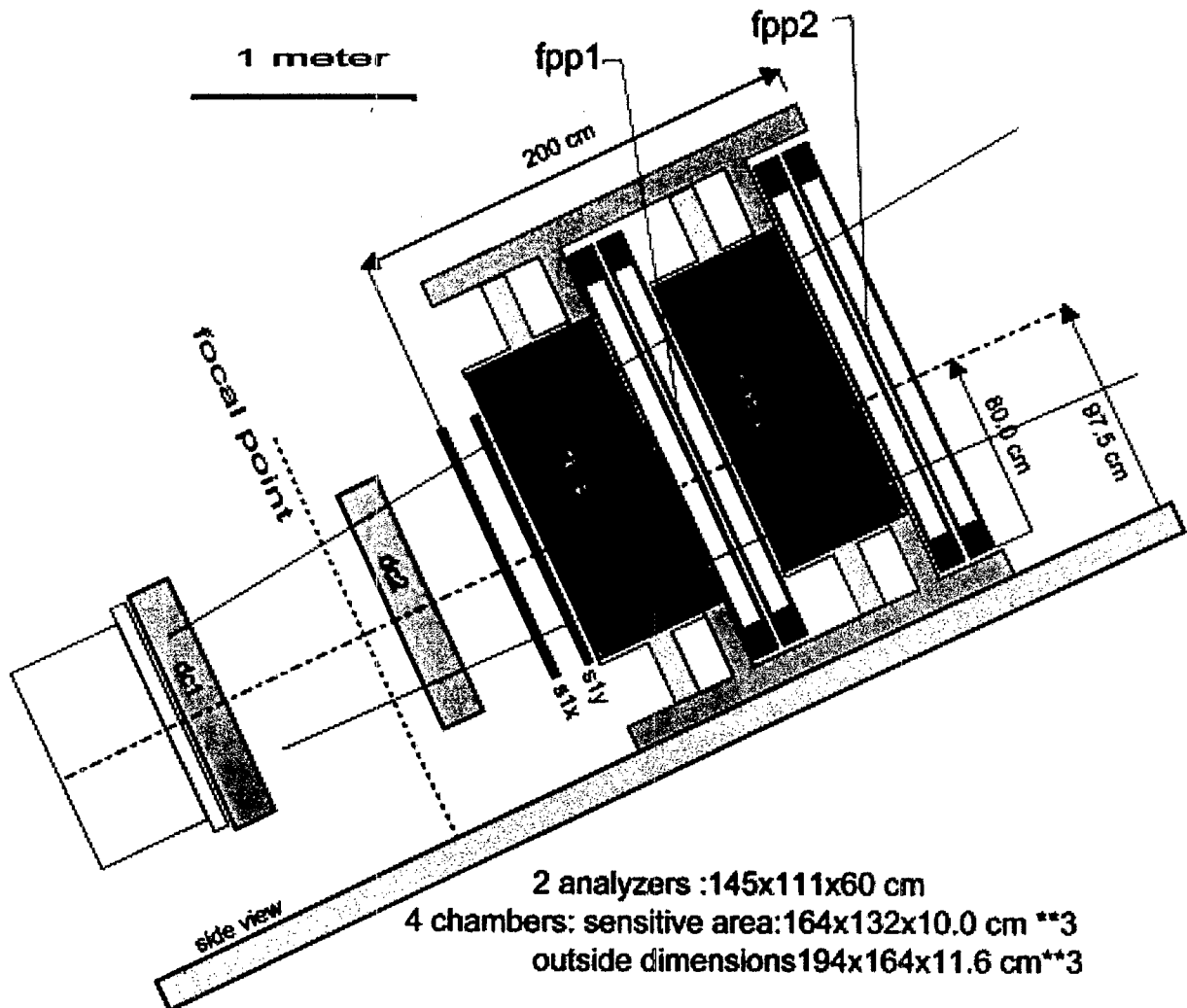


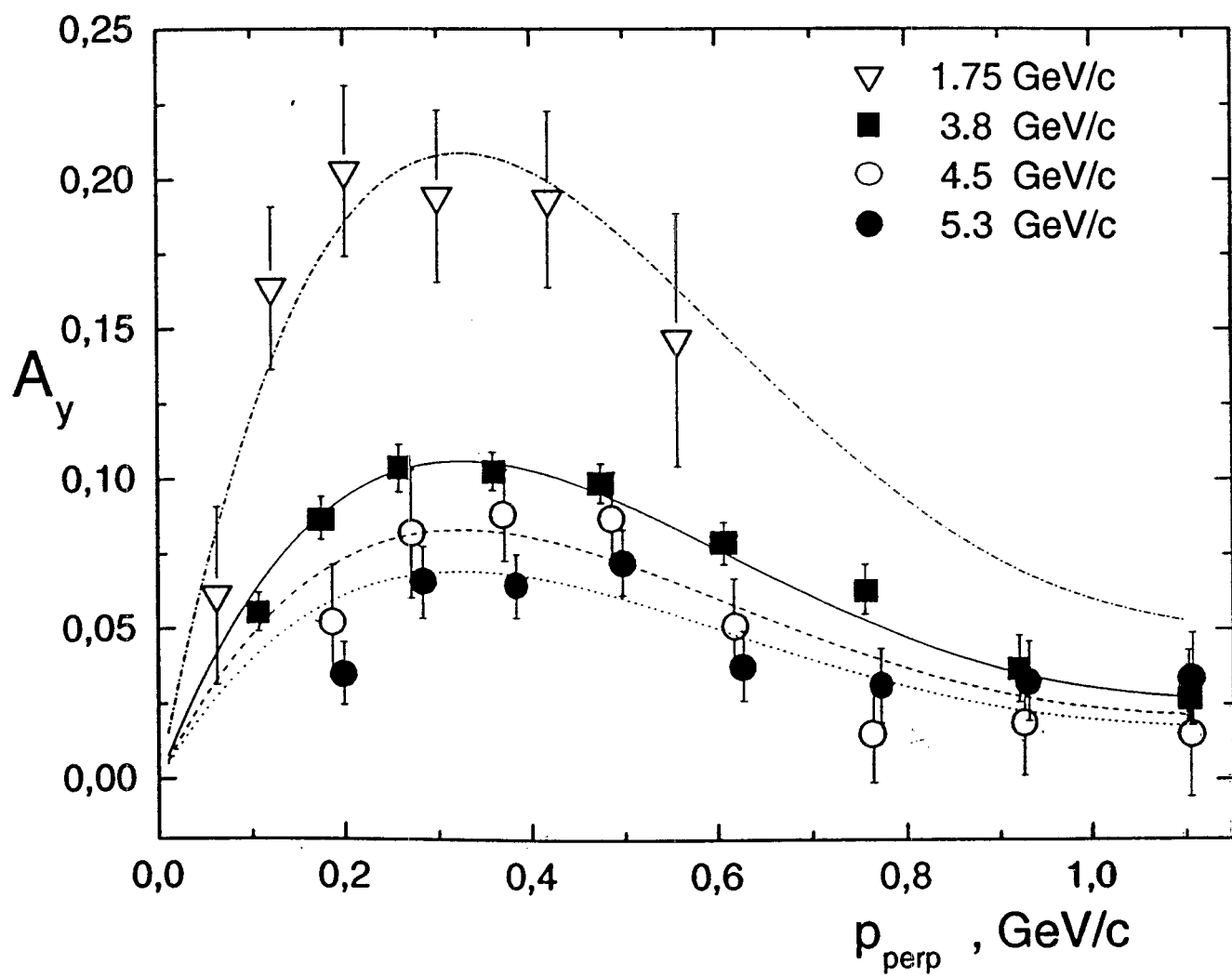


# 01-109 Calorimeter



## FPP for 01-109 in Hall C





# REMARKS

The form factors of the nucleon are **the** observables; they are **related** to charge and magnetization distributions.

However the relation is non-trivial; the distributions are not directly observable:

They are not frame independent, and their transformation involves more than kinematics

They are affected by the vector meson which probes them and distorts.

The comparison of data with theoretical predictions can only be done with the form factors.

# CONCLUSIONS

The data base for the form factors of the proton have been transformed by the results of the 2 Hall A experiments.

Most theoretical models can readily accomodate the quasi linear decrease of  $\mu_p G_{Ep} / G_{Mp}$

Relativity plays a crucial role in getting the observed slope, and all modern models are relativistic.

The pioneer work of G. Miller's group predicted the Jlab data, and implicitly had the right Q-dependence for  $F_2/F_1$ . So did the soliton model calculation of G. Holzwarth.

We have an alternate explanation from J. Ralston, who sees the  $1/Q$  behavior of  $F_2 / F_1$  as due to contribution of non-zero orbital momentum quark states.

In a few years we should have  $\mu_p G_{Ep} / G_{Mp}$  from Hall C to 9 GeV<sup>2</sup>. At this point we do not have any prediction of the results: zero crossing and gentle flattening (a la pQCD) are both possibilities.

“Fitting” the proton form factor data does not give us a true understanding of its structure.

All nucleon form factors must be reproduced

only a handful of models have a prediction of the neutron and proton electric form factors

the difficulty of measuring  $G_{En}$  may have discouraged our theoretical colleagues to venture in this direction.

The perspective of a measurement of  $G_{En}$  at  $Q^2 = 3.4 \text{ GeV}^2$  at Jlab in Hall A should be stimulating.